# AN INVESTIGATION OF THE ENGINEERING CHARACTERISTICS OF THE VOLCANIC LACUSTRINE CLAY DEPOSIT BENEATH MEXICO CITY

BY

LEONARDO ZEEVAERT

C. E. Universidad Nacional de Mexico, 1939

S. M. Massachusetts Institute of Technology, 1940

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ENGINEERING IN THE GRADUATE COLLEGE OF THE UNIVERSITY OF ILLINOIS, 1949

URBANA, ILLINOIS

# AN INVESTIGATION OF THE ENGINEERING CHARACTERISTICS OF THE VOLCANIC LACUSTRINE CLAY DEPOSIT BENEATH MEXICO CITY

BY

LEONARDO ZEEVAERT

C. E. Universidad Nacional de Mexico, 1939

S. M. Massachusetts Institute of Technology, 1940

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ENGINEERING IN THE GRADUATE COLLEGE OF THE UNIVERSITY OF ILLINOIS, 1949

URBANA, ILLINOIS

## ACKNOWLEDGEMENT

The author wishes to express his gratitude to the University of Illinois for inviting him to become a Visiting Research Associate in the Engineering Experiment Station and the Department of Civil Engineering, and subsequently a Fellow in the Graduate College in the Department of Civil Engineering.

He also wishes to express his sincere appreciation to Professor W. C. Huntington, Head of the Department of Civil Engineering; to Dr. Karl Terzaghi, Lecturer and Research Consultant in Civil Engineering; and to Dr. R. B. Peck, Research Professor of Soil Mechanics, for their assistance in providing the facilities of the University of Illinois for carrying out these studies.

He is especially indebted to Dr. Terzaghi for giving him continuous encouragement ever since the author first had the priviledge of his acquaintance, and to Dr. Peck for his advice and constructive suggestions.

Further acknowledgement is due to Dr. R. E. Grim, of the Illinois State Geological Survey, for studies concerning the mineralogy of Mexico City clay; to the author's several colleagues in Mexico City for their cooperation in obtaining valuable field and laboratory information; and to the University of Mexico for granting the author a leave of absence as Professor of Soil Mechanics.

R. UNIV.
BIBLIOTHEEK
LEIDEN

# INTRODUCTION

The design of building foundations in Mexico City has developed on the basis of experience since the establishment of the city in 1325, when the Aztecs drove stakes into the silty bottom of the lake to provide stable basis for their structures. However, even today very large settlements may take place if the strength of the clay is overestimated. No satisfactory solution to the problem of the foundation engineer can be anticipated without a scientific study of the character of the soil deposit. Such a study is the purpose of this thesis.

The data for the study was taken from the author's personal records and observations during eight years of active practice in foundation engineering in Mexico City. Other basic information, primarily concerning observations in the field since 1325, was obtained from several references as indicated in the text. This information was very helpful in developing the background of geological and historical considerations which are of vital importance to an understanding of the phenomena observed at the present time.

## CONTENT AND CONCLUSION

The aim of the study had two purposes: (1) to provide the foundation engineer with all the information available to the author on the engineering properties of the lacustrine clays beneath Mexico City; and (2) to draw conclusions concerning the behavior of the natural clay deposit as a contribution to soil mechanics and foundation engineering, with the hope that they may stimulate further research on highly sensitive clays.

The following factors contributing to the behavior of the volcanic clay deposit beneath Mexico City were considered:

a. the geological history of the lacustrine deposits.
b. the loading history of the city area.
c. the physical properties of the clay deposit.
d. the causes of the ground subsidence of the city.
e. the behavior of existing foundations.

One of the principal conclusions, necessary to an understanding of the complex behavior of foundations in Mexico City, was the discovery that the clay has experienced a high degree of physico-chemical hardening. The process of hardening that began in the first stages of sedimentation and continued thereafter during subsequent consolidation of the soft clay deposit may be satisfactorily explained by Professor Terzaghi's theory of solidification.

The pressure corresponding to the break in the compressibility curves obtained from normal consolidation tests was found not to agree with the total effective pressure including the artificial reduction in buoyancy in the mass of clay, in contrast to the usual behavior of normally loaded clay deposits. In general, an increment of stress may be added to the total effective pressure before a breakdown of the virgin structure of the clay takes place. This fact, verified by field observations, led the author to the concept of the "critical load." When the total effective stress remains less than the critical load, the clay may be treated, for practical purposes, as pre-compressed. When it becomes greater, the clay becomes very compressible. Thus it is of vital importance to learn the variation of the critical load with depth for the natural clay deposit.

The favorable drainage conditions in the clay deposit, and the high permeability of the clay itself, combine to cause the primary consolidation, to be almost complete by the end of the construction period for a building. Thereafter, the settlement decreases with time according to a logarithmic law. To evaluate this effect, the secondary time-factor was introduced and found to be a function of pressure. The author then expressed the coefficient of volume compressibility as a function of the time and of the secondary time-factor.

The thesis contains information concerning the geological history of the lacustrine deposits beneath Mexico City. The loading history of the city since its foundation by the Aztecs is thoroughly discussed. The results of an extensive study of the physical properties of the clay are presented by means of statistical relationships. Finally a discussion is presented of the causes of the ground subsidence of Mexico City, and of the behavior of raft and pile foundations.

The following items are believed to represent original contributions of the author.

a. The geology of the subsoil beneath the city.

b. The interpretation of the geological profiles to indicate two periods of large subsidence in Mexico City since its establishment in 1325.

c. The comprehensive study of the physical properties of the clay and the various statistical relationships among these properties.

d. The establishment of the concept of the existence of the critical load, and its importance to the foundation engineer.

e. The discovery that the settlement of structures in Mexico City is due almost exclusively to the phenomenon commonly called secondary compression, and the development of an approximate method of settlement prediction based upon empirical considerations.

f. The establishment of the fact that the ordinary methods of settlement computations based upon the concept of primary consolidation are not applicable in Mexico City if the pressure in the subsoil is less than the critical load.

g. The presentation of information to demonstrate that the driving of piles into the soft volcanic clay does not lead to significant disturbance except in the immediate vicinity of each pile.

h. The presentation of evidence that the outlying portions of Mexico City may be entering a third period of large settlement and that this settlement may be seriously increased by the extraction of water from the subsoil by means of wells.

# VITA

NAME: Leonardo Zeevaert.

PLACE OF BIRTH: Veracruz, Ver., Mexico.

DATE OF BIRTH: November 27, 1914.

INSTITUTIONS ATTENDED:

Universidad Nacional de Mexico ---------- 1933-1937

Massachusetts Institute of Technology ---------- 1939-1940

University of Illinois ---------- 1947-1949

DEGREES AND HONORS:

Civil Engineer Degree, from Universidad Nacional de Mexico ---------- 1939

Master of Science in Civil Engineering Degree from Massachusetts Institute of Technology ---------- 1940

Associate Member of the Society of Sigma Xi ---------- 1940

Junior ASCE ---------- 1941

Member Associacion de Ingenieros y Arquitectos de Mexico 1941

Member American Concrete Institute ---------- 1942

Member Colegio de Ingenieros ---------- 1947

Visiting Research Associate Structural Engineering, Department of Civil Engineering, University of Illinois ---------- 1947-1948

Special Research Fellow Civil Engineering, University of Illinois ---------- 1948-1949

Member of the Society of Sigma Xi ---------- 1949

Associate Member, ASCE ---------- 1949

PUBLICATIONS:

Un Metodo Sencillo para el Calculo de las Estructuras Indeterminadas, Ingenieria Julio 1939.

Determinacion de las Lineas Isopaquicas en Fotoelasticidad, Ingenieria, Febrero 1941.

El Uso de los Modelos de Alambre en el Analisis de Estructuras Indeterminadas, Irrigacion en Mexico, Mayo 1942.

Flujo en los Materiales de Tierra Anisotropos, Ingenieria Julio 1942.

Aplicacion de la Mecanica de los Suelos al Estudio de las Excavaciones en Arcillas Saturadas, Ingenieria, Noviembre 1942.

Ecuaciones de Condicion en las Estructuras Hiperestaticas, Irrigacion en Mexico, Septiembre 1943.

Discussion, Application of Soil Mechanics in Designing Building Foundations, Trans, ASCE., Vol. 109 (1944).

Conceptos y Experimentos Fundamentales que se Aplican al Diseno de Cimentaciones en Arcillas Saturadas, Arquitectura e Ingenieria, Mayo 1945.

Equilibrio Elastico-Plastico en la Superficie de Contacto Entre un Suelo Arcilloso y una Placa Rigida, Congreso Mexicano de Matematicas Aplicadas, (1946).

La Torsion en los Edificios Sujetos a Temblor, Ingenieria y Arquitectura, 1947.

Outline of a Mat Foundation Design on Mexico City Clay, Seventh Texas Conference on Soil Mechanics and Foundations, January 1947.

Discussion, Effect of Driving Piles in Soft Clay, Proc. ASCE. May 1949.

Present Foundation Problems in Mexico City, Presented at the July Meeting of the ASCE. in Mexico City, 1949.

TECHNICAL AND PROFESSIONAL EXPERIENCE:

Professor Soil Mechanics and Foundations, Universidad Nacional de Mexico. ---------- 1941-1947

Assistant Bridge Engineer, Direccion Nacional de Caminos, SCOP. ---------- 1937-1939

Consulting Engineer, Experimental Station, Comision Nacional Irrigacion ---------- 1941-1945

Consulting Engineer, Foundations and Structures in Mexico ---------- 1941-1949